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(54) Electrostatic actuator and camera module using the same

(57) An electrostatic actuator comprises a first stator section (1) having a first electrode array (12) arranged in a first direction, and a second stator section (2) having a second electrode array (22) of electrodes formed in the first direction. A movable section (3) having a fifth electrode (33) and a sixth electrode 34 arranged to face the first electrode array (12) and the second electrode array (22), respectively, is arranged between the first stator section (1) and the second stator section (2). A driving circuit (4) alternately performs a first driving operation in which a DC voltage is applied between the adjacent electrodes of the first electrode array (12) and a second driving operation in which a DC voltage is applied between the electrodes of the second electrode array (22). The voltage application is successively performed by deviating the positions of the electrodes to which the DC voltage is applied by the first driving operation so as to move the movable section (3) in the first direction while vibrating the movable section (3) between the first stator section (1) and the second stator section (2).

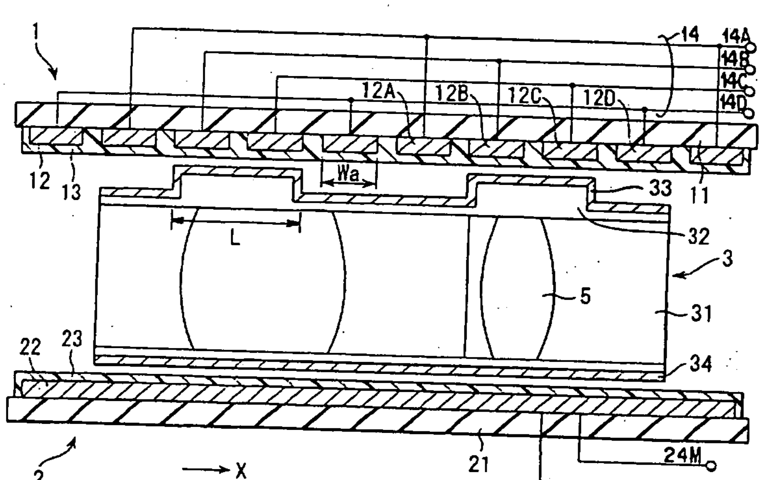

FIG. 1A

Description

[0001] The present invention relates to an electrostatic actuator for driving a movable section arranged between a pair of stator sections by utilizing an electrostatic force (Coulomb force), particularly, to an electrostatic actuator that makes it unnecessary to use an electric wiring connected to the movable section and a camera module using the particular electrostatic actuator in the focus adjusting mechanism.

[0002] An electrostatic actuator comprising a movable section arranged between a pair of stator sections, said movable section being driven by an electrostatic force (Coulomb force), is disclosed in, for example, Japanese Patent Disclosure (Kokai) No. 8-140367. The conventional electrostatic actuator disclosed in this prior art comprises a first stator section and a second stator section, which are arranged to face each other, and a movable section arranged between these first and second stator sections. A first electrode array consisting of a plurality of electrodes arranged at a predetermined pitch in the longitudinal direction is mounted to the first stator section. Also, a second electrode array consisting of a plurality of electrodes arranged at a predetermined pitch in the longitudinal direction is mounted to the second stator section. It should be noted, however, that the phase of the electrodes of the first electrode array is deviated from the phase of the electrodes of the second electrode array by a 1/2 pitch.

[0003] To be more specific, the electrodes of each of the first electrode array and the second electrode array are divided on the imaginary basis into four groups A, B, C and D, with every two electrodes in the arranging direction forming a single group, and a DC voltage is applied between the electrodes of each of these groups and the electrodes on the movable section.

[0004] In the conventional electrostatic actuator disclosed in this prior art, the driving operations (1) and (2) given below are alternately repeated:

(1) A DC voltage is applied between the first electrode array and the electrode mounted to the movable section so as to attract electrostatically the movable section toward the first stator section; and
(2) A DC voltage is applied between the second electrode array and the electrode mounted to the movable section so as to attract electrostatically the movable section toward the second stator section.

[0005] By the driving operation given above, the movable section is macroscopically moved successively in the longitudinal direction of the stator sections by 1/2 pitch of the electrode array while being vibrated microscopically between the first stator section and the second stator section. The moving direction of the movable section can be changed by changing the order of applying a DV voltage to the electrodes of groups A, B, C and D. Specifically, the movable section can be moved in a first direction by applying a DC voltage to the electrodes of groups A and B, the electrodes of groups B and C, the electrodes of groups C and D, and the electrodes of group D in the order mentioned. Also, the movable section can be moved in a second direction opposite to said first direction by applying a DC voltage to the electrodes of groups D and C, the electrodes of groups C and B, the electrodes of groups B and A, and the electrodes of group A in the order mentioned.

[0006] In the conventional electrostatic actuator, utilized is the electrostatic force generated when a DC voltage is applied between the electrode arrays on the stator sections and the electrode on the movable section so as to make it absolutely necessary to mount an electrical wiring to not only the electrode arrays on the stator sections but also to the electrode on the movable section. Since it is necessary to mount an electrical wiring to the movable section, the mass production capability of the electrostatic actuator is impaired. Also, since the space for the wiring is required, the miniaturization of the electrostatic actuator is impaired. Further, since the movable section is moved frequently, stress is applied to the wiring to the electrode on the movable section, with the result that the reliability is lowered during use of the electrostatic actuator over a long time.

[0007] It should also be noted that, in the conventional electrostatic actuator, a dielectric film is formed on the electrode as a measure against the insulation breakdown. What should be noted is that the dielectric polarization is generated in the dielectric film when a DC voltage is applied between the electrode arrays on the stator sections and the electrode on the movable section. The dielectric polarization produces the force for keeping the movable section, which is attracted to one of the stator sections, attracted to the particular stator section. The potential difference produced by the dielectric polarization is small. However, since the distance between the movable section and the stator section is small, it is possible for the force produced by the dielectric polarization to become larger than the electrostatic force produced between the electrode on the other stator section and the electrode on the movable section, with the result that the normal moving operation of the movable section tends to be obstructed.

[0008] As described above, in the conventional electrostatic actuator, in which the movable section is moved by utilizing the electrostatic force generated when a DC voltage is applied between the electrode array on the stator section and the electrode on the movable section, it is absolutely necessary to mount an electrical wiring to the electrode on the movable section so as to give rise to the problems that the mass production capability of the electrostatic actuator is lowered, that the electrostatic actuator is rendered bulky because of the requirement of the space occupied by the electrical wiring, and that the reliability of the electrostatic actuator is lowered over a long time.

[0009] In addition, the conventional electrostatic ac-

array being maintained at the first and second levels during the second period, respectively,
the third DC voltage signal being applied to the adjacent second and third electrodes of the first electrode array to attract the first electrode section of the movable section during a third period, the second and third electrodes of the first electrode array being maintained at the first and second levels during the third period, respectively,
the fourth DC voltage signal being applied to the adjacent fifth and sixth electrodes of the second electrode array to attract the second electrode section of the movable section during a fourth period, the fifth and sixth electrodes of the second electrode array being maintained at the first and second levels during the fourth period, respectively, and
the movable section being moved in the first direction in accordance with the application of the first, second, third and fourth DC voltage signals.

[0016] According to a third aspect of the present invention, there is provided an electrostatic actuator, comprising:

a first stator section including first and second electrode arrays each including first, second and third electrodes and arranged substantially in parallel and at a predetermined pitch in a first direction;
a second stator section arranged to face the first stator section and to define a space between the first and second stator sections, and including a third electrode array including fourth and fifth electrodes
a movable section arranged in the space and including a first electrode section facing the first electrode array and a second electrode section facing the second electrode array, the first and second electrode sections being maintained at a predetermined floating potential; and
a driving circuit configured to apply DC voltage signals to the first and second electrode arrays and the third electrode array, alternatively, the DC voltage signal having a first level higher than the predetermined floating potential and a second level lower than the predetermined floating potential,
the first DC voltage signal being applied to the first electrodes of the first and second electrode arrays to attract the first electrode section of the movable section during a first period, the first electrodes of the first and second electrode arrays being maintained at the first and second levels during the first period, respectively,
the second DC voltage signal being applied to the fourth and fifth electrodes of the third electrode array to attract the second electrode section of the movable section during a second period,
the third DC voltage signal being applied to the second electrodes of the first and second electrode arrays to attract the first electrode section of the movable section during a third period, the second electrodes of the first and second electrode arrays being maintained at the first and second levels during the third period, respectively, and the movable section being moved in the first direction in accordance with the application of the first, second and third DC voltage signals.

[0017] According to a fourth aspect of the present invention, there is provided an electrostatic actuator, comprising:

a first stator section including first and second electrode arrays each including first and second electrodes and arranged substantially in parallel and at a predetermined pitch in a first direction;
a second stator section arranged to face the first stator section and to define a space between the first and second stator sections, and including third and fourth electrode arrays each including third and fourth electrodes and arranged substantially in parallel and at a predetermined pitch in the first direction, the third and fourth electrode array being arranged at the same pitch as that of the first and second electrode arrays in the first direction and the arrangement of the third and fourth electrode arrays being deviated by the half of the predetermined pitch from the arrangement of the first and second electrode arrays;
a movable section arranged in the space and including a first electrode section facing the first and second electrode arrays and a second electrode section facing the third and fourth electrode arrays, the first and second electrode sections being maintained at a predetermined floating potential; and
a driving circuit configured to apply DC voltage signals to the first, second, third and fourth electrode arrays, alternatively, the DC voltage signal having a first level higher than the predetermined floating potential and a second level lower than the predetermined floating potential,
the first DC voltage being applied to the first electrodes of the first and second electrode arrays to attract the first electrode section of the movable section during a first period, the first electrodes of the first and second electrode arrays being maintained at the first and second levels during the first period, respectively,
the second DC voltage being applied to the third electrodes of the third and fourth electrode arrays to attract the second electrode section of the movable section during a second period, the third electrodes of the third and fourth electrode arrays being maintained at the first and second levels during the second period, respectively,
the third DC voltage being applied to the second electrodes of the first and second electrode arrays

od, the second and third electrodes of the first electrode array being maintained at the first and second levels during the third period, respectively,

the fourth DC voltage signal being applied to the fourth and fifth electrodes of the second electrode array to attract the second electrode section of the movable section during a fourth period, the fourth electrode of the second electrode array being maintained at one of the first and second levels during the fourth period, and the fifth electrode of the second electrode array being maintained at the other of first and second levels during the fourth period, and

the movable section being moved in the first direction in accordance with the application of the first, second, third and fourth DC voltage signals;

a lens mounted in the movable section and movable with the movable section, configured to transfer the picture image; and

an image pick-up element configured to receive the transferred picture image to generate a image signal.

[0020] According to a seventh aspect of the present invention, there is provided a camera module for photographing a picture image, comprising:

an electrostatic actuator, including:

a first stator section including a first electrode array including first, second and third electrodes arranged at a predetermined pitch in a first direction;

a second stator section arranged to face the first stator section and to define a space between the first and second stator sections, and including a second electrode array including fourth, fifth and sixth electrodes arranged at the predetermined pitch in the first direction;

a movable section arranged in the space and including a first electrode section facing the first electrode array and a second electrode section facing the second electrode array, the first and second electrode sections being maintained at a predetermined floating potential; and

a driving circuit configured to apply DC voltage signals to the first and second electrode arrays, alternatively, the DC voltage signal having a first level higher than the predetermined floating potential and a second level lower than the predetermined floating potential,

the first DC voltage signal being applied to the adjacent first and second electrodes of the first electrode array to attract the first electrode section of the movable section during a first period, the first and second electrodes of the first electrode array being maintained at the first and second levels during the first period, respectively,

the second DC voltage signal being applied to the adjacent fourth and fifth electrodes of the second electrode array to attract the second electrode section of the movable section during a second period, the fourth and fifth electrodes of the second electrode array being maintained at the first and second levels during the second period, respectively,

the third DC voltage signal being applied to the adjacent second and third electrodes of the first electrode array to attract the first electrode section of the movable section during a third period, the second and third electrodes of the first electrode array being maintained at the first and second levels during the third period, respectively,

the fourth DC voltage signal being applied to the adjacent fifth and sixth electrodes of the second electrode array to attract the second electrode section of the movable section during a fourth period, the fifth and sixth electrodes of the second electrode array being maintained at the first and second levels during the fourth period, respectively, and

the movable section being moved in the first direction in accordance with the application of the first, second, third and fourth DC voltage signals;

a lens mounted in the movable section and movable with the movable section, configured to transfer the picture image; and

an image pick-up element configured to receive the transferred picture image to generate a image signal.

[0021] According to a eighth aspect of the present invention, there is provided a camera module for photographing a picture image, comprising:

an electrostatic actuator, including:

a first stator section including first and second electrode arrays each including first and second electrodes and arranged substantially in parallel and at a predetermined pitch in a first direction;

a second stator section arranged to face the first stator section and to define a space between the first and second stator sections, and including third and fourth electrode arrays each including third and fourth electrodes and arranged substantially in parallel and at a predetermined pitch in the first direction, the third and fourth electrode array being arranged at the same pitch as that of the first and second elec-

the third period, and the movable section being moved in the first direction in accordance with the application of the first, second and third DC voltage signals;
a lens mounted in the movable section and movable with the movable section, configured to transfer the picture image; and
an image pick-up element configured to receive the transferred picture image to generate a image signal.

[0023] This summary of the invention does not necessarily describe all necessary features so that the invention may also be a sub-combination of these described features.

[0024] The invention can be more fully understood from the following detailed description when taken in conjunction with the accompanying drawings, in which:

FIGS. 1A and 1B are cross sectional views schematically showing the construction of the electrostatic actuator according to a first embodiment of the present invention in a longitudinal direction of the electrostatic actuator and in a direction perpendicular to the longitudinal direction, respectively;
FIG. 2 schematically shows the constructions of the first electrode array and the second electrode array on the first stator section and the second stator section shown in FIGS. 1A and 1B, respectively, as well as the construction of the driving circuit;
FIGS. 3A to 3F are timing charts for describing the operation of the electrostatic actuator shown in FIGS. 1A and 1B;
FIG 4 schematically shows how the first step is performed for operating the electrostatic actuator shown in FIGS. 1A and 1B;
FIG 5 schematically shows how the second step is performed for operating the electrostatic actuator shown in FIGS. 1A and 1B;
FIG 6 schematically shows how the third step is performed for operating the electrostatic actuator shown in FIGS. 1A and 1B;
FIG. 7 schematically shows how the fourth step is performed for operating the electrostatic actuator shown in FIGS. 1A and 1B;
FIG. 8 is a cross sectional view schematically showing the construction of the electrostatic actuator according to a second embodiment of the present invention in a longitudinal direction of the electrostatic actuator;
FIG. 9 schematically shows the constructions of the first electrode array and the second electrode array on the first stator section and the second stator section shown in FIG. 8, respectively, as well as the construction of the driving circuit;
FIGS. 10A to 10H are timing charts for describing the operation of the electrostatic actuator shown in FIG. 8;
FIG. 11 schematically shows how the first step is performed for operating the electrostatic actuator shown in FIG. 8;
FIG. 12 is a plan view schematically showing the construction of the electrode array on the first stator section in an electrostatic actuator according to a third embodiment of the present invention;
FIGS. 13A to 13J are timing charts for describing the operation of the electrostatic actuator shown in FIG. 12;
FIG. 14 is a plan view schematically showing the construction of the first electrode array on the first stator section included in an electrostatic actuator according to a fourth embodiment of the present invention;
FIG. 15 is a plan view schematically showing the construction of the first electrode array on the first stator section included in an electrostatic actuator according to a fifth embodiment of the present invention;
FIG. 16A and 16B are a plan view schematically showing the construction of the first and second electrode arrays on the first and second stator sections included in an electrostatic actuator according to a sixth embodiment of the present invention;
FIGS. 17A to 17H are timing charts for describing the operation of the electrostatic actuator shown in FIG. 16;
FIG. 18 is a plan view schematically showing the construction of the first electrode array on the first stator section included in an electrostatic actuator according to a seventh embodiment of the present invention;
FIG. 19 is a plan view schematically showing the construction of the first electrode array on the first stator section included in an electrostatic actuator according to a eighth embodiment of the present invention;
FIG. 20 is a plan view schematically showing the construction of the first electrode array on the first stator section included in an electrostatic actuator according to an ninth embodiment of the present invention; and
FIG. 21 is a plan view showing a small electronic camera module according to a tenth embodiment of the present invention, which is a modification of the electrostatic actuator of the present invention.

[0025] Some embodiments of the present invention will now be described with reference to the accompanying drawings.

(First Embodiment)

[0026] FIGS. 1A and 1B collectively show the construction of an electrostatic actuator according to a first embodiment of the present invention; wherein FIG. 1A is a cross sectional view showing the electrostatic actu-

the switching circuits 43, 44 in accordance with a drive instruction signal S1 and a direction instruction signal S2 generated from, for example, a host computer (not shown).

[0034] The operation of the electrostatic actuator according to the first embodiment of the present invention will now be described with reference to the time charts shown in FIGS. 3A to 3F and to the operating states shown in FIGS. 4 to 7. FIGS. 3A to 3F show the wave forms of the voltages applied to the electrodes 12A, 12B, 12C, 12D, 22M and 22N, and FIGS. 4 to 7 show how the movable section 3 is moved.

[0035] In starting the operation, the drive instruction signal S1 is supplied to the switch control circuit 45 so as to render the driving circuit 4 active. At the same time, the direction instruction signal S2 is supplied to the switch control circuit 45 so as to determine whether the movable section 3 is moved to the right or to the left in FIG. 1A. The following description is on the basis that the movable section 3 is moved to the right unless otherwise pointed out specifically.

[0036] In response to the drive instruction signal S1 and the direction instruction signal S2, a positive voltage and a negative voltage are applied from the DC voltage source 41 to the electrode 12A and the electrode 12B, respectively, through the switching circuit 43 for a predetermined period T1, as shown in FIGS. 3A and 3B. In this stage, the electrode 12A, the fifth electrode 33 and the electrode 12B collectively form a series circuit including two capacitors, and a line E1 of electric force runs through the electrode 12A, the fifth electrode 33 and the electrode 12B. It should be noted that the line E1 of electric force tends to shrink as much as possible. As a result, an electrostatic attractive force is generated between the electrodes 12A, 12B and the fifth electrode 33 so as to cause the movable section 3 to be moved toward the first stator section 1.

[0037] In the next step, positive and negative voltages are applied from the DC voltage source 42 to the electrode 22M and 22N, respectively, through the switching circuit 44 for a predetermined period T2, as shown in FIGS. 3E and 3F. In this stage, the circuit formed of the electrode 22M, the sixth electrode 34 and the electrode 22N corresponds to an equivalent series circuit including two capacitors so as to generate a line E2 of electric force running through the electrode 22M, the sixth electrode 34 and the electrode 22N, as shown in FIG. 5. The line E2 of electric force thus generate also tends to shrink and, thus, an electrostatic attractive force is generated between the electrode 22M, 22N and the sixth electrode 34. It follows that the movable section 3 is moved toward the second stator section 2.

[0038] Further, a positive voltage and a negative voltage are applied to the electrode 12B and the electrode 12C, respectively, during a period T3 as shown in FIGS. 3B and 3C. As a result, line E3 of electric force is generated to run through the electrode 12B, the fifth electrode 33 and the electrode 12C, and an electrostatic attractive force is generated between the electrodes 12B, 12C and the fifth electrode 33. It follows that the movable section 3 is moved toward the first stator section 1. It should be noted that the electrodes 12B, 12C included in the first electrode array 12 and having voltages applied thereto are deviated by one pitch (P) from the electrodes 12A, 12B to which the voltages were applied previously during the period T1. It follows that the movable section 3 is moved to the right by one pitch P when moved toward the first stator section 2.

[0039] In the next step, a positive voltage and a negative voltage are applied to the electrode 22N and the electrode 22M, respectively, during a period T4, as shown in FIGS. 3E and 3F. As a result, a line E4 of electric force is generated to run through the electrode 22N, the sixth electrode 34 and the electrode 22M so as to generate an electrostatic attractive force between the electrodes 22M, 22N and the sixth electrode 34. It follows that the movable section 3 is moved toward the second stator section.

[0040] Likewise, a positive voltage and a negative voltage are applied to the electrode 12C and the electrode 12D, respectively, during a period T5, as shown in FIGS. 3C and 3D and, then, a positive voltage and a negative voltage are applied to the electrode 22M and the electrode 22N, respectively, during a period T6 like during the period T2, as shown in FIGS. 3E and 3F. Then, a positive voltage and a negative voltage are applied to the electrode 12D and the electrode 12A, respectively, during a period T7, as shown in FIGS. 3D and 3A and, then, a positive voltage and a negative voltage are applied to the electrode 22N and the electrode 22M, respectively, during a period T8 like during the period T4, as shown in FIGS. 3E and 3F. The operations described above are successively performed so as to finish the operation of one period T consisting of the periods T1 to T8 referred to above.

[0041] By the operation described above, the movable section 3 is successively moved macroscopically pitch by pitch in the arranging direction (X-direction) of the first electrode array 12 on the first stator section 1, i.e., to the right in FIG. 1A, while being vibrated microscopically between the first stator section 1 and the second stator section 2.

[0042] Where the direction instruction signal S2 instructing the movement of the movable section 3 to the right in FIG. 1A is supplied to the switch control circuit 45, the DC voltage is applied successively between the electrodes 12D and 12A, between the electrodes 22M and 22N, between the electrodes 12C and 12C, between the electrodes 22N and 22M, between the electrodes 12B and 12C, between the electrodes 22M and 22N, between the electrodes 12A and 12B, and between the electrodes 22N and 22M from the period T8 toward the period T1 shown in FIGS. 3A to 3F. As a result, the movable section 3 is successively moved macroscopically to the left in FIG. 1A while being vibrated between the first stator section 1 and the second stator

[0049] As shown in FIG. 9, the driving circuit 4 includes two DC voltage sources 41, 42, two switching circuits 43, 44 serving to switch the DC voltage signals generated from the DC voltage sources 41, 42 so as to generate rectangular wave form voltage signals, and a switch control circuit 45 serving to control the outputs of the rectangular wave form voltage signals generated from the switching circuits 43, 44. The switching circuit 43 serving to connect the first electrode array 12 to the DC voltage source 41 via the wiring 14 includes an input terminal and an output terminal. The output generated from the output terminal is controlled by a control signal generated from the switch control circuit 45 and supplied to the input terminal. Likewise, the switching circuit 44 serving to connect the second electrode array 22 to the DC voltage source 42 includes an input terminal and an output terminal. The output generated from the output terminal is controlled by a control signal generated from the switch control circuit and supplied to the input terminal. The switch control circuit 45 is constructed to control the switching circuits 43, 44 in accordance with a drive instruction signal S1 and a direction instruction signal S2 generated from, for example, a host computer (not shown).

[0050] The operation of the electrostatic actuator according to the second embodiment of the present invention will now be described with reference to the time charts shown in FIGS. 10A to 10H and to the operating states shown in FIG. 11. FIGS. 10A to 10H show the wave forms of the voltages applied to the electrodes 12A, 12B, 12C, 12D, 22E, 22F, 22G and 22H, and FIG. 11 show how the movable section 3 is moved.

[0051] In starting the operation, the drive instruction signal S1 is supplied to the switch control circuit 45 so as to render the driving circuit 4 active. At the same time, the direction instruction signal S2 is supplied to the switch control circuit 45 so as to determine whether the movable section 3 is moved to the right or to the right in FIG. 8. The following description is on the basis that the movable section 3 is moved to the right unless otherwise pointed out specifically.

[0052] In response to the drive instruction signal S1 and the direction instruction signal S2, a positive voltage and a negative voltage are applied from the DC voltage source 41 to the electrode 12A and the electrode 12B, respectively, through the switching circuit 43 for a predetermined period T1, as shown in FIGS. 11A and 11B. In this stage, the electrode 12A, the electrode 33 and the electrode 12B collectively form a series circuit including two capacitors, and lines E1 of electric force run through the electrode 12A, the electrode 33 and the electrode 12B. It should be noted that the lines E1 of electric force tends to shrink as much as possible. As a result, an electrostatic attractive force is generated between the electrodes 12A, 12B and the electrode 33 so as to cause the movable section 3 to be moved toward the first stator section 1.

[0053] In the next step, positive and negative voltages are applied from the DC voltage source 42 to the electrode 22G and 22H, respectively, through the switching circuit 44 for a predetermined period T2, as shown in FIGS. 10G and 10H. In this stage, the circuit formed of the electrode 22G, the electrode 34 and the electrode 22H corresponds to an equivalent series circuit including two capacitors so as to generate lines E2 of electric force running through the electrode 22G, the electrode 34 and the electrode 22H. The lines E2 of electric force thus generate also tends to shrink and, thus, an electrostatic attractive force is generated between the electrode 22G, 22H and the electrode 34. It follows that the movable section 3 is moved toward the second stator section 2. The electrodes 22G, 22H of the first electrode array 22, to which positive and negative voltages are applied, are deviated by P/2 pitch from the electrodes 12A and 12B of the first electrode array 12 to which voltages have been applied during the period T1. Thus, the movable section 3 is moved by P/2 pitch in the right direction at the time of moving the movable section 2 from the first stator section 12 toward the second stator section 22.

[0054] Further, a positive voltage and a negative voltage are applied to the electrode 12B and the electrode 12C, respectively, during a period T3 as shown in FIGS. 10B and 10C. As a result, lines E3 of electric force are generated to run through the electrode 12B, the electrode 33 and the electrode 12C, and an electrostatic attractive force is generated between the electrodes 12B, 12C and the electrode 33. It follows that the movable section 3 is moved toward the first stator section 1. It should be noted that the electrodes 12B, 12C included in the first electrode array 12 and having voltages applied thereto are deviated by one pitch (P) from the electrodes 12A, 12B to which the voltages were applied previously during the period T1. It follows that the movable section 3 is moved to the right when moved toward the first stator section 2.

[0055] In the next step, a positive voltage and a negative voltage are applied to the electrode 22E and the electrode 22H, respectively, during a period T4, as shown in FIGS. 10E and 10H. As a result, lines E4 of electric force are generated to run through the electrode 22E, the electrode 34 and the electrode 22H so as to generate an electrostatic attractive force between the electrodes 22E, 22H and the electrode 34. It follows that the movable section 3 is moved toward the second stator section 22.

[0056] Likewise, a positive voltage and a negative voltage are applied to the electrode 12C and the electrode 12D, respectively, during a period T5, as shown in FIGS. 10C and 10D and, then, a positive voltage and a negative voltage are applied to the electrode 22E and the electrode 22F, respectively, during a period T6 like during the period T2, as shown in FIGS. 10E and 10F. Then, a positive voltage and a negative voltage are applied to the electrode 12D and the electrode 12A, respectively, during a period T7, as shown in FIGS. 10D

the electrode 12A+ as shown in FIG. 13A, a negative voltage is applied to the electrode 12A- as shown in FIG. 13B, a positive voltage is applied to the electrode 12B+ as shown in FIG. 13C, and a negative voltage is applied to the electrode 12B- as shown in FIG. 13D. In this stage, each of the circuit formed of the electrode 12A+, the fifth electrode 33 and the electrode 12A- and the circuit formed of the electrode 12B+, the fifth electrode 33 and the electrode 12B-forms an equivalent series circuit including two capacitors. As a result, generated are lines of electric force running through the route consisting of the electrode 12A+, the fifth electrode 33, and the electrode 12A- and the route consisting of the electrode 12B+, the fifth electrode 33 and the electrode 12B-. Since these lines of electric force tend to shrink as much as possible, an electrostatic attractive force is generated between the electrodes 12A+, 12A-, 12B+, 12B- and the fifth electrode 33, with the result that the movable section 3 is moved toward the first stator section 1.

[0065] In the next step, a positive voltage is applied to the electrode M22 as shown in FIG. 13I and a negative voltage is applied to the electrode N22 as shown in FIG. 13J. In this stage, the circuit formed of the electrode M22, the sixth electrode 34 and the electrode N22 corresponds to a series equivalent circuit including two capacitors and, thus, lines of electric force are formed to run through the electrode M22, the sixth electrode 34 and the electrode N22. Since the lines of electric force thus formed tend to shrink as much as possible, an electrostatic attractive force is generated between the electrodes M22, N22 and the sixth electrode 34, with the result that the movable section 3 is moved toward the second stator section 2.

[0066] In the next step, which is not absolutely necessary, the voltages of the polarity opposite to that of the voltages applied during the period T1 are applied during a period T3 such that a negative voltage is applied to the electrode 12A+, a positive voltage is applied to the electrode 12A-, a negative voltage is applied to the electrode 12B+, and a positive voltage is applied to the electrode 12B-. Further, the voltages of the polarity opposite to that of the voltages applied during the period T2 are applied during a period T4 such that a negative voltage is applied to the electrode 22M, a positive voltage is applied to the electrode 22N. Since the voltages of the polarity opposite to that of the voltages applied during the periods T1 and T2 are applied to the electrodes 12A+, 12A-, 12B+, 12B-, 22M and 22N during the periods T3 and T4, the charge generated by the dielectric polarization of the dielectric films 13, 23 formed as a measure against the insulation breakdown is discharged, with the result that the moving operation of the movable section 3 is prevented from being rendered unstable by the dielectric polarization.

[0067] Then, a positive voltage is applied to the electrode 12B+ as shown in FIG. 13B, a negative voltage is applied to the electrode 12B- as shown in FIG. 13D, a positive voltage is applied to the electrode 1CB+ as shown in FIG. 13E and a negative voltage is applied to the electrode 12C- as shown in FIG. 13F. In this stage, an electrostatic attractive force is generated between the electrodes 12B+, 12B-, 12C+, 12c- and the third electrode 3e3, with the result that the movable section 3 is moved toward the first stator section 2. It should be noted that the electrodes 12B+, 12B-, 12C+, 12C- of the first electrode array 12 to which the voltage is applied are deviated by one pitch from the electrodes 12A+, 12A-, 12B+, 12B- to which the voltage was applied previously during the period T1. It follows that the movable section 3 is moved to the right by one pitch when moved toward the first stator section 1. Then, a positive voltage is applied to the electrode M22 and a negative voltage is applied to the electrode N22 during a period T6 as shown in FIGS. 9I and 9J. As a result, an electrostatic attractive force is generated between the electrodes 22M, 22N and the sixth electrode 34, with the result that the movable section 3 is moved toward the second stator section 2.

[0068] Further, the voltages of the polarity opposite to that of the voltages applied during the periods T5 and T6 are applied during a period T7 as during the periods T3 and T4 such that a negative voltage is applied to the electrode 12B+ as shown in FIG. 13C, a positive voltage is applied to the electrode 12B- as shown in FIG. 13D, a negative voltage is applied to the electrode 12C+ as shown in FIG. 13E, and a positive voltage is applied to the electrode 12C- as shown in FIG. 13F. Then, a negative voltage is applied to the electrode M22 and a positive voltage is applied to the electrode N22 during a period T8 as shown in FIGS. 9I and 9J so as to cancel the charge produced by the dielectric polarization of the dielectric films 13, 23. It follows that the moving operation of the movable section 3 is prevented from being rendered unstable by the dielectric polarization.

[0069] Similarly, a first driving operation in which a DC voltage is applied to two sets of the electrodes 12A+, 12B+, 12C+, 12D+ of the first electrode group 12-1 of the first electrode array 12 and the electrodes 12A-, 12B-, 12C-, 12D- of the second electrode group 12-2 of the first electrode array 12 and a second driving operation in which a DC voltage is applied to the electrodes M22, N22 are alternately repeated. In addition, the positions of the electrodes of the first electrode group 12-1 are successively deviated by one pitch from the electrodes of the second electrode group 12-2 during periods T9 to T12 such that the driving operation for one period T is finished by the periods T1 to T12.

[0070] By the driving operation described above, the movable section 3 is macroscopically moved to the right while being vibrated microscopically between the first stator section 1 and the second stator section 2, as in the first embodiment. If the order of applying the DC voltage to the electrodes is made opposite to that described above, the movable section 3 can be moved to the left in FIG. 12.

[0071] The third embodiment described above pro-

able section 3 is moved toward the second stator section 2.

[0078] In the next step, a positive voltage is applied to the electrode 12C+ and a negative voltage is applied to the electrode 12C- for a predetermined period so as to generate an electrostatic attractive force between the electrodes 12C+, 12C- and the fifth electrode 33, with the result that the movable section 3 is moved toward the first stator section 1. Then, a negative voltage is applied to the electrode 22M and a positive voltage is applied to the electrode 22N so as to generate an electrostatic attractive force between the electrodes 22M, 22N and the sixth electrode 34, with the result that the movable section 3 is moved toward the second stator section 2. It should be noted that the positions of the electrodes 12C+ and 12C- of the first electrode array 12 to which the voltages are applied are deviated by 1/2 pitch (P/2) from the positions of the electrodes 12A+ and 12A- to which the voltages were applied previously, with the result that the movable section 3 is moved by P/2 to the right when moved toward the second stator section 2.

[0079] Likewise, a positive voltage is applied to the electrode 12B+ and a negative voltage is applied to the electrode 12B for a predetermined period so as to generate an electrostatic attractive force between the electrodes 12B+, 12B- and the fifth electrode 33, with the result that the movable section 3 is moved toward the first stator section 1. Then, a positive voltage is applied to the electrode 22M and a negative voltage is applied to the electrode 22N so as to generate an electrostatic attractive force between the electrodes 22M, 22N and the sixth electrode 34, with the result that the movable section 3 is moved toward the second stator section 2. Further a positive voltage is applied to the electrode 12D+ and a negative voltage is applied to the electrode 12D- for a predetermined period so as to generate an electrostatic attractive force between the electrodes 12D+, 12D- and the fifth electrode 33, with the result that the movable section 3 is moved toward the first stator section 1. Then, a negative voltage is applied to the electrode 22M and a positive voltage is applied to the electrode 22N so as to generate an electrostatic attractive force between the electrodes 22M, 22N and the sixth electrode 34, with the result that the movable section 3 is moved toward the second stator section 2.

[0080] By the driving operation described above, the movable section 3 is macroscopically moved to the right while being vibrated microscopically between the first stator section 1 and the second stator section 2, as in the first embodiment. If the order of applying the DC voltage to the electrodes is made opposite to that described above, the movable section 3 can be moved to the left in FIG. 14.

[0081] The fourth embodiment described above produces the effects similar to those produced by the first embodiment described previously. Also, in the first embodiment, the movement resolution of the movable section 3 (i.e., the moving distance per step) is equal to the electrode arranging pitch P of the first electrode array 12. In the fourth embodiment, however, the movement resolution of the movable section 3 is half the electrode arranging pitch P of the first electrode array 12 so as to make it possible to achieve the movement of a higher accuracy.

[0082] It should also be noted that, in the fourth embodiment of the present invention, the connection between the electrode and the pad can be achieved by a planar wiring in place of a steric wiring so as to improve the mass production capability of the electrostatic actuator.

(Fifth Embodiment)

[0083] FIG. 15 is a plan view showing the first electrode array 12 on the first stator section 1 included in an electrostatic actuator according to a fifth embodiment of the present invention. In the fifth embodiment of the present invention, two electrode groups are further added to the first electrode array 12 used in the fourth embodiment of the present invention. To be more specific, the first electrode array 12 in the fifth embodiment includes a first electrode group 12-1 consisting of the electrodes 12A+ and 12B+, a second electrode group 12-2 consisting of the electrodes 12A- and 12B-, a third electrode group 12-3 consisting of the electrodes 12C+ and 12D+, a fourth electrode group 12-4 consisting of the electrodes 12C- and 12D-, a fifth electrode group 12-5 consisting of the electrodes 12E+ and 12F+, and a sixth electrode group 12-6 consisting of the electrodes 12E- and 12F-,. These electrode groups 12-1, 12-2, 12-3, 12-4, 12-5 and 12-6 are arranged in the order mentioned.

[0084] The electrodes of the electrode groups 12-1 and 12-2 have an electrically paired relationship and are arranged to extend in the X-direction at the same pitch P and under the same phase. Likewise, the electrodes of the electrode groups 12-3 and 12-4 have an electrically paired relationship and are arranged to extend in the X-direction at the same pitch P and under the same phase. Further, the electrodes of the electrode groups 12-5 and 12-6 have an electrically paired relationship and are arranged to extend in the X-direction at the same pitch P and under the same phase. However, the phase of the electrodes of the electrode groups 12-5 and 12-6 is deviated by 1/3 pitch (P/3) from the phase of the electrodes of the electrode groups 12-3 and 12-4 and, thus, is deviated by 2/3 pitch (2P/3) from the phase of the electrodes of the electrode groups 12-1 and 12-2.

[0085] On the other hand, the second electrode array 22 on the second stator section 2 consists of two band-like electrodes 22M and 22N formed on the substrate 21 a predetermined distance apart from each other and extending in the longitudinal direction (first direction) of the substrate 21. Further, the third electrode 34 is formed in six rows on the movable section 3 in a manner to correspond to the electrode groups 12-1, 12-2, 12-3,

12D+, the electrode 12D-, respectively.

[0096] In the first step, a positive voltage is applied to the electrode 12A+ on the first stator section 1 and a negative voltage is applied to the electrode 12A- on the first stator section 1 during a period T1 as shown in FIGS. 17A and 17B. In this stage, the circuit consisting of the electrode 12A+, the fifth electrode 33 and the electrode 12A- equivalently corresponds to a series circuit including two capacitors so as to generate lines of electric force running through the electrode 12A+, the fifth electrode 33 and the electrode 12A-. Since the lines of electric force thus generated tend to shrink as much as possible, an electrostatic attractive force is generated between the electrodes 12A+, 12A- and the fifth electrode 33, with the result that the movable section 3 is moved toward the first stator section 1.

[0097] Then, a positive voltage is applied to the electrode 12C+ on the second stator section 2 and a negative voltage is applied to the electrode 12C- on the second stator section 2 during a period T2 as shown in FIGS. 17E and 17F. In this stage, the circuit consisting of the electrode 12C+, the sixth electrode 34 and the electrode 12C- equivalently corresponds to a series circuit including two capacitors so as to generate lines of electric force running through the electrode 12C+, the sixth electrode 34 and the electrode 12C-. Since the lines of electric force thus generated tend to shrink as much as possible, an electrostatic attractive force is generated between the electrodes 12C+, 12C- and the fifth electrode 33, with the result that the movable section 3 is moved toward the second stator section 2. It should be noted that the phase of the electrodes 12C+, 12C- is deviated by P/2 from the phase of the electrodes 12A+, 12A-, with the result that the movable section 3 is moved to the right in FIG. 16 by P/2 when moved to the second stator section 2.

[0098] In the next step, a positive voltage is applied to the electrode 12B+ on the first stator section 1 and a negative voltage is applied to the electrode 12B- on the first stator section 1 during a period T3 as shown in FIGS. 17C and 17D. In this stage, lines of electric force are generated in a manner to run through the electrode 12B+, the fifth electrode 33 and the electrode 12B-. As a result, an electrostatic attractive force is generated between the electrodes 12B+, 12B- and the fifth electrode 33, with the result that the movable section 3 is moved toward the first stator section 1. It should be noted that the phase of the electrodes 12B+, 12B- is deviated by P/2 from the phase of the electrodes 12A+, 12A-, with the result that the movable section 3 is moved to the right in FIG. 16 by P/2 when moved to the first stator section 1.

[0099] Then, a positive voltage is applied to the electrode 12D+ on the second stator section 2 and a negative voltage is applied to the electrode 12D- on the second stator section 2 during a period T4 as shown in FIGS. 17G and 17H. As a result, lines of electric force are generated to run through the electrode 12D+, the sixth electrode 34 and the electrode 12D-, and an electrostatic attractive force is generated between the electrodes 12D+, 12D- and the sixth electrode 34, with the result that the movable section 3 is moved toward the second stator section 2. It should be noted that the phase of the electrodes 12D+, 12D- is deviated by P/2 from the phase of the electrodes 12C+, 12C-, with the result that the movable section 3 is moved to the right in FIG. 16 by P/2 when moved to the second stator section 2.

[0100] By the driving operation described above, the movable section is macroscopically moved to the right in FIG. 16 while being vibrated microscopically between the first stator section and the second stator section. The movable section 3 can be moved to the left in FIG. 16 by making opposite the order of applying a DV voltage to the electrodes.

[0101] Likewise, a DC voltage is applied successively to the electrode 12A+, the electrode 12A-, the electrode 12B+, the electrode 12B-, the electrode 12C+, the electrode 12C-, the electrode 12D+ and the electrode 12D- during periods T4 to T8, and the driving operation of one period T is finished by the periods T1 to T8. It should be noted in this connection that the polarity of the DC voltage applied during the periods T5 to T8 is opposite to that of the DC voltage applied during the periods T1 to T4, as apparent from FIGS. 17A to 17H, with the result that the charge produced by the dielectric polarization of the dielectric films 13, 23 is canceled as in the embodiments described previously. It follows that the moving operation of the movable section 3 is prevented from being rendered unstable by the dielectric polarization.

(Seventh Embodiment)

[0102] FIG. 18 is a plan view showing the first electrode array 12 on the first stator section 1 according to a seventh embodiment of the present invention. The seventh embodiment of the present invention differs from the sixth embodiment in that the first electrode group 12-1 in the sixth embodiment consisting of the electrodes 12A+ and 12B+ is divided into electrode groups 12-1A and 12-B, and these electrode groups 12-1A and 12-B are arranged on both sides of the second electrode group 12-2 consisting of the electrodes 12A-and 12B-. The electrodes belonging to the same group of the divided electrode groups 12-1A and 12-1B are commonly connected by wirings, and these divided electrode groups 12-1A and 12-B collectively perform the function of a single electrode group.

[0103] On the other hand, the phase of the electrodes of the second electrode array (not shown) on the second stator section 2 is deviated by 1/2 pitch from the phase of the electrodes of the first electrode array as in the sixth embodiment. The driving operation of the seventh embodiment is equal to that of the sixth embodiment and, thus, the description is omitted in respect of the driving operation of the seventh embodiment.

trode array (22), the first and second electrode sections (33, 34) being maintained at a predetermined floating potential; and
a driving circuit (4) configured to apply DC voltage signals to the first and second electrode arrays (12, 22), alternatively, the DC voltage signal having a first level higher than the predetermined floating potential and a second level lower than the predetermined floating potential,
the first DC voltage signal being applied to the adjacent first and second electrodes (12A, 12B, 12C, 12D) of the first electrode array (12) to attract the first electrode section (33) of the movable section (3) during a first period, the first and second electrodes (12A, 12B, 12C, 12D) of the first electrode array (12) being maintained at the first and second levels during the first period, respectively,
the second DC voltage signal being applied to the fourth and fifth electrodes (22, 22M, 22N, 22E, 22F, 22G, 22H) of the second electrode array (22) to attract the second electrode section (34) of the movable section (3) during a second period, the fourth and fifth electrodes (22, 22M, 22N, 22E, 22F, 22G, 22H) of the second electrode array (22) being maintained at the first and second levels during the second period, respectively,
the third DC voltage signal being applied to the adjacent second and third electrodes (12A, 12B. 12C, 12D) of the first electrode array (12) to attract the first electrode section (33) of the movable section (3) during a third period, the second and third electrodes (12A, 12B, 12C, 12D) of the first electrode array (12) being maintained at the first and second levels during the third period, respectively,
the fourth DC voltage signal being applied to the fourth and fifth electrodes (22, 22M, 22N, 22E. 22F, 22G, 22H) of the second electrode array (22) to attract the second electrode section (34) of the movable section (3) during a fourth period, the fourth electrode (22, 22M, 22N. 22E, 22F, 22G, 22H) of the second electrode array (22) being maintained at one of the first and second levels during the fourth period, and the fifth electrode (22, 22M, 22N, 22E, 22F, 22G, 22H) of the second electrode array (22) being maintained at the other of first and second levels during the fourth period, and
the movable section (3) being moved in the first direction in accordance with the application of the first, second, third and fourth DC voltage signals.

2. The electrostatic actuator according to claim 1, **characterized in that**:

the first electrode array (12) further includes a sixth electrode,
the fifth DC voltage signal being applied to the adjacent third and sixth electrodes (12A, 12B, 12C, 12D) of the first electrode array (12) to attract the first electrode section'(33) of the movable section (3) during a fifth period, the third and sixth electrodes (12A, 12B, 12C, 12D) of the first electrode array (12) being maintained at the first and second levels during the fifth period, respectively.

3. The electrostatic actuator according to either of claims 1 or 2, **characterized in that**:

the movable section (3) has concave and convex portions faced to the first electrode array (12), the first electrode section (33) of the movable section (3) formed on the convex portion.

4. An electrostatic actuator, **characterized by** comprising:

a first stator section (1) including a first electrode array (12) including first, second and third electrodes (12A, 12B, 12C, 12D) arranged at a predetermined pitch in a first direction;
a second stator section (2) arranged to face the first stator section (1) and to define a space between the first and second stator sections (1, 2), and including a second electrode array (22) including fourth, fifth and sixth electrodes (22E, 22F, 22G, 22H) arranged at the predetermined pitch in the first direction;
a movable section (3) arranged in the space and including a first electrode section (33) facing the first electrode array (12) and a second electrode section (34) facing the second electrode array (22), the first and second electrode sections (33, 34) being maintained at a predetermined floating potential; and
a driving circuit (4) configured to apply DC voltage signals to the first and second electrode arrays (12, 22), alternatively, the DC voltage signal having a first level higher than the predetermined floating potential and a second level lower than the predetermined floating potential,
the first DC voltage signal being applied to the adjacent first and second electrodes (12A, 12B, 12C, 12D) of the first electrode array (12) to attract the first electrode section (33) of the movable section (3) during a first period, the first and second electrodes (12A, 12B, 12C, 12D) of the first electrode array (12) being maintained at the first and second levels during the first period, respectively,
the second DC voltage signal being applied to the adjacent fourth and fifth electrodes (22E,

third electrode array (22) to attract the second electrode section (34) of the movable section (3) during a second period,
the third DC voltage signal being applied to the second and third electrodes (12A+, 12B+, 12C+, 12D+, 12A-, 12B-, 12C-, 12D-) of the first and second electrode arrays (12, 12-1, 12-2) to attract the first electrode section (33) of the movable section (3) during a third period, the second and third electrodes (12A+, 12B+, 12C+, 12D+, 12A-, 12B-, 12C-, 12D-) of the first and second electrode arrays (12, 12-1, 12-2) being maintained at the first and second levels during the third period, respectively, and the movable section (3) being moved in the first direction in accordance with the application of the first, second and third DC voltage signals.

9. The electrostatic actuator according to claim 8, **characterized in that**:

the first and second electrodes (22M, 22N) of the third electrode array (22) are extended in the first direction.

10. The electrostatic actuator according to claim 9, **characterized in that**:

the first and second electrode arrays (12, 12-1, 12-2) further includes sixth electrodes (12A+, 12B+, 12C+, 12D+, 12A-, 12B-, 12C-, 12D-),
the fourth DC voltage signal is applied to the fourth and fifth electrodes (22M, 22N) of the third electrode array (22) to attract the second electrode section (34) of the movable section (3) during a fourth period, and
the fifth DC voltage signal is applied to the sixth electrodes (12A+, 12B+, 12C+, 12D+, 12A-, 12B-, 12C-, 12D-) of the first and second electrode arrays (12, 12-1, 12-2) to attract the second electrode section (34) of the movable section (3) during a fifth period.

11. An electrostatic actuator, **characterized by** comprising:

a first stator section (1) including first and second electrode arrays (12, 12-1, 12-2) each including first and second electrodes (12A+, 12B+, 12A-, 12B-) and arranged substantially in parallel and at a predetermined pitch in a first direction;
a second stator section (2) arranged to face the first stator section (1) and to define a space between the first and second stator sections (1, 2), and including third and fourth electrode arrays (22, 22-1, 22-2) each including third and fourth electrodes (22C+, 22D+, 22C-, 22D-) and arranged substantially in parallel and at a predetermined pitch in the first direction, the third and fourth electrode array (22, 22-1, 22-2) being arranged at the same pitch as that of the first and second electrode arrays (12, 12-1, 12-2) in the first direction and the arrangement of the third and fourth electrode arrays (22, 22-1, 22-2) being deviated by the half of the predetermined pitch from the arrangement of the first and second electrode arrays (12, 12-1, 12-2);
a movable section (3) arranged in the space and including a first electrode section (33) facing the first and second electrode arrays (12, 12-1, 12-2) and a second electrode section (34) facing the third and fourth electrode arrays (22, 22-1, 22-2), the first and second electrode sections (33, 34) being maintained at a predetermined floating potential; and
a driving circuit (4) configured to apply DC voltage signals to the first, second, third and fourth electrode arrays(12, 12-1, 12-2, 22, 22-1, 22-2), alternatively, the DC voltage signal having a first level higher than the predetermined floating potential and a second level lower than the predetermined floating potential,
the first DC voltage being applied to the first electrodes (12A+, 12B+, 12A-, 12B-) of the first and second electrode arrays (12, 12-1, 12-2) to attract the first electrode section (33) of the movable section (3) during a first period, the first electrodes (12A+, 12B+, 12A-, 12B-) of the first and second electrode arrays (12, 12-1, 12-2) being maintained at the first and second levels during the first period, respectively,
the second DC voltage being applied to the third electrodes (22C+, 22D+, 22C-, 22D-) of the third and fourth electrode arrays (22, 22-1, 22-2) to attract the second electrode section (34) of the movable section (3) during a second period, the third electrodes of the third and fourth electrode arrays being maintained at the first and second levels during the second period, respectively,
the third DC voltage being applied to the second electrodes (12A+, 12B+, 12A-, 12B-) of the first and second electrode arrays (12, 12-1, 12-2) to attract the first electrode section (33) of the movable section (3) during a third period, the second electrodes (12A+, 12B+, 12A-, 12B-) of the first and second electrode arrays (12, 12-1, 12-2) being maintained at the first and second levels during the third period, respectively,
the fourth DC voltage being applied to the fourth electrodes (22C+, 22D+, 22C-, 22D-) of the third and fourth electrode arrays (22, 22-1, 22-2) to attract the second electrode section

the movable section (3) has concave and convex portions faced to the first electrode array (12), the first electrode section (33) of the movable section (3) formed on the convex portion.

16. A camera module for photographing a picture image, **characterized by** comprising:

an electrostatic actuator, including:

a first stator section (1) including a first electrode array (12) including first, second and third electrodes (12A, 12B, 12C, 12D) arranged at a predetermined pitch in a first direction;
a second stator section (2) arranged to face the first stator section (1) and to define a space between the first and second stator sections (1, 2), and including a second electrode array (22) including fourth and fifth electrodes (22, 22M, 22N, 22E, 22F, 22G, 22H);
a movable section (3) arranged in the space and including a first electrode section (33) facing the first electrode array (12) and a second electrode section (34) facing the second electrode array (22), the first and second electrode sections (33, 34) of the movable section (3) being maintained at a predetermined floating potential; and
a driving circuit (4) configured to apply DC voltage signals to the first and second electrode arrays (12, 22), alternatively, the DC voltage signal having a first level higher than the predetermined floating potential and a second level lower than the predetermined floating potential,
the first DC voltage signal being applied to the adjacent first and second electrodes of the first electrode array (12) to attract the first electrode section (33) of the movable section (3) during a first period, the first and second electrodes of the first electrode array (12) being maintained at the first and second levels during the first period, respectively,
the second DC voltage signal being applied to the fourth and fifth electrodes of the second electrode array (22) to attract the second electrode section (34) of the movable section (3) during a second period,
the third DC voltage signal being applied to the adjacent second and third electrodes of the first electrode array (12) to attract the first electrode section (33) of the movable section (3) during a third period, the second and third electrodes of the first electrode array (12) being maintained at the first and second levels during the third period, respectively, and the movable section (3) being moved in the first direction in accordance with the application of the first, second and third voltage signals.

a lens (5) mounted in the movable section (3) and movable with the movable section (3), configured to transfer the picture image; and
an image pick-up element (101) configured to receive the transferred picture image to generate a image signal.

17. A camera module for photographing a picture image, **characterized by** comprising:

an electrostatic actuator, including:

a first stator section (1) including a first electrode array (12) including first, second and third electrodes (12A, 12B, 12C, 12D) arranged at a predetermined pitch in a first direction;
a second stator section (2) arranged to face the first stator section (1) and to define a space between the first and second stator sections (1, 2), and including a second electrode array (22) including fourth, fifth and sixth electrodes (22E, 22F, 22G, 22H) arranged at the predetermined pitch in the first direction;
a movable section (3) arranged in the space and including a first electrode section (33) facing the first electrode array (12) and a second electrode section (34) facing the second electrode array (22), the first and second electrode sections (33, 34) being maintained at a predetermined floating potential; and
a driving circuit (4) configured to apply DC voltage signals to the first and second electrode arrays (12, 22), alternatively, the DC voltage signal having a first level higher than the predetermined floating potential and a second level lower than the predetermined floating potential,
the first DC voltage signal being applied to the adjacent first and second electrodes (12A, 12B, 12C, 12D) of the first electrode array (12) to attract the first electrode section (33) of the movable section (3) during a first period, the first and second electrodes (12A, 12B, 12C, 12D) of the first electrode array (12) being maintained at the first and second levels during the first period, respectively,
the second DC voltage signal being applied to the adjacent fourth and fifth elec-

the fourth DC voltage being applied to the fourth electrodes (22C+, 22D+,22C-, 22D-) of the third and fourth electrode arrays (22, 22-1, 22-2) to attract the second electrode section (34) of the movable section (3) during a fourth period, the fourth electrodes (22C+, 22D+,22C-, 22D-) of the third and fourth electrode arrays (22, 22-1, 22-2) being maintained at the third and fourth levels during the fourth period, respectively, and the movable section (3) being moved in the first direction in accordance with the application of the first, second, third and fourth DC voltage signals.

a lens (5) mounted in the movable section (3) and movable with the movable section (3), configured to transfer the picture image; and
an image pick-up element (101) configured to receive the transferred picture image to generate a image signal.

19. A camera module for photographing a picture image, **characterized by** comprising:

an electrostatic actuator, including:

a first stator section (1) including first, second and third electrode arrays (12, 12-1, 12-2, 12-3) each including first and second electrodes (12A+, 12A-, 12B+, 12B-) and arranged substantially in parallel and at a predetermined pitch in a first direction;
a second stator section (2) arranged to face the first stator section (1) and to define a space between the first and second stator sections (1, 2), and including a fourth electrode array (22) including third and fourth electrodes (22M, 22N);
a movable section (3) arranged in the space and including a first electrode section (33) facing the first, second and third electrode arrays (12) and a second electrode section (34) facing the fourth electrode array (22), the first and second electrode sections (33, 34) being maintained at a predetermined floating potential; and
a driving circuit (4) configured to apply DC voltage signals to the first, second, third and fourth electrode arrays (12, 12-1, 12-2, 12-3, 22), alternatively, the DC voltage signal having a first level higher than the predetermined floating potential and a second level lower than the predetermined floating potential,
the first DC voltage signal being applied to the first electrodes (12A+, 12A-, 12B+, 12B-) of the first, second and third electrode arrays (12, 12-1, 12-2, 12-3) to attract the first electrode section (33) of the movable section (3) during a first period, the first electrodes (12A+, 12A-, 12B+, 12B-) of the first and third electrode arrays (12, 12-1, 12-2, 12-3) being maintained at one of the first and second levels during the first period and the first electrode (12A+, 12A-, 12B+, 12B-) of the second electrode array (12, 12-2) being maintained at the other of the first and second levels during the first period,
the second DC voltage signal being applied to the third and fourth electrodes (22M, 22N) of the fourth electrode array (22) to attract the second electrode section (34) of the movable section (3) during a second period,
the third DC voltage signal being applied to the second electrodes (12A+, 12A-, 12B+, 12B-) of the first, second and third electrode arrays (12, 12-1, 12-2, 12-3) to attract the first electrode section (33) of the movable section (3) during a third period, the second electrodes (12A+, 12A-, 12B+, 12B-) of the first and third electrode arrays (12, 12-1, 12-2, 12-3) being maintained at one of the first and second levels during the third period, the second electrodes (12A+, 12A-, 12B+, 12B-) of the second electrode array (12, 12-2) being maintained at the other of the first and second levels during the third period, and the movable section (3) being moved in the first direction in accordance with the application of the first, second and third DC voltage signals.

a lens (5) mounted in the movable section (3) and movable with the movable section (3), configured to transfer the picture image; and
an image pick-up element (101) configured to receive the transferred picture image to generate a image signal.

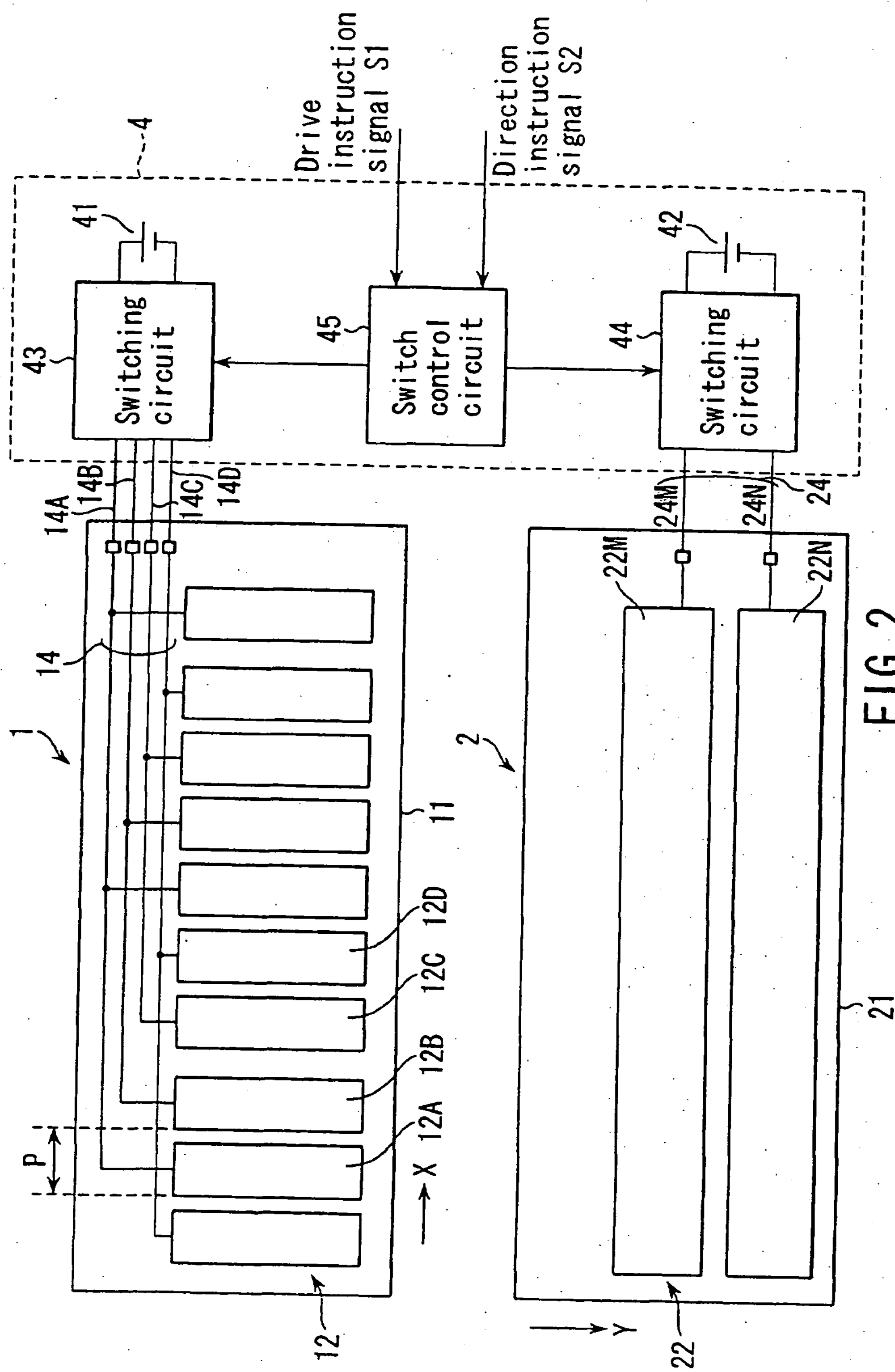
Drive instruction signal S1
Direction instruction signal S2
4
41
42
43
44
45
Switching circuit
Switch control circuit
Switching circuit
14A
14B
14C
14D
14
24M
24N
24
22M
22N
1
2
11
12D
12C
12B
12A
12
P
X
Y
22
21

FIG. 2

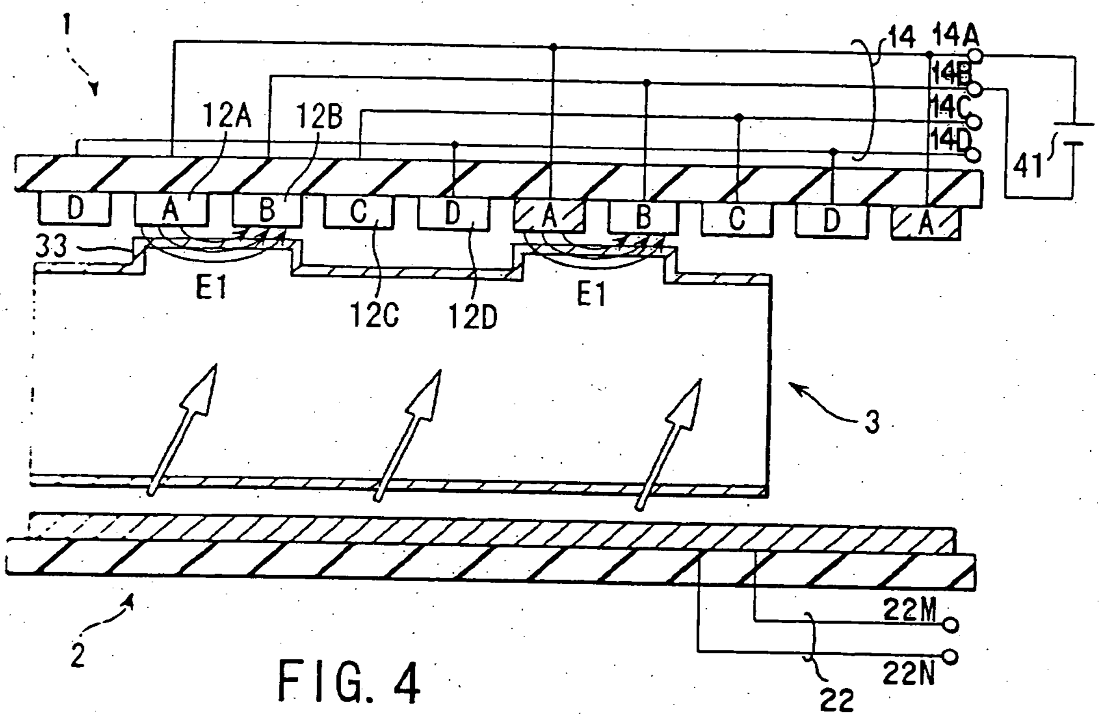
1
12A
12B
14
14A
14B
14C
14D
41
D
A
B
C
D
A
B
C
D
A
33
E1
12C
12D
E1
3
2
22M
22N
22

FIG. 4

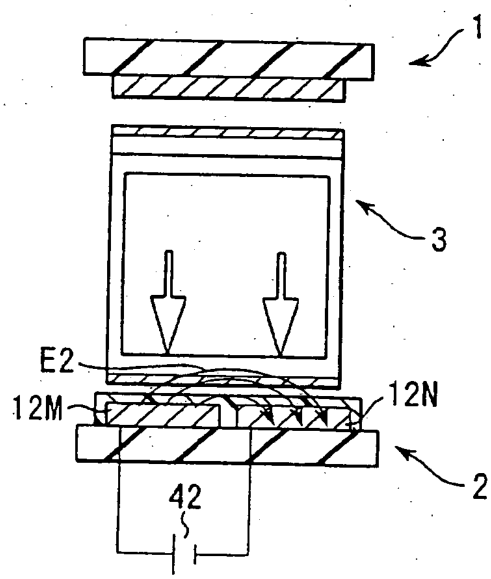
1
3
E2
12M
12N
2
42

FIG. 5

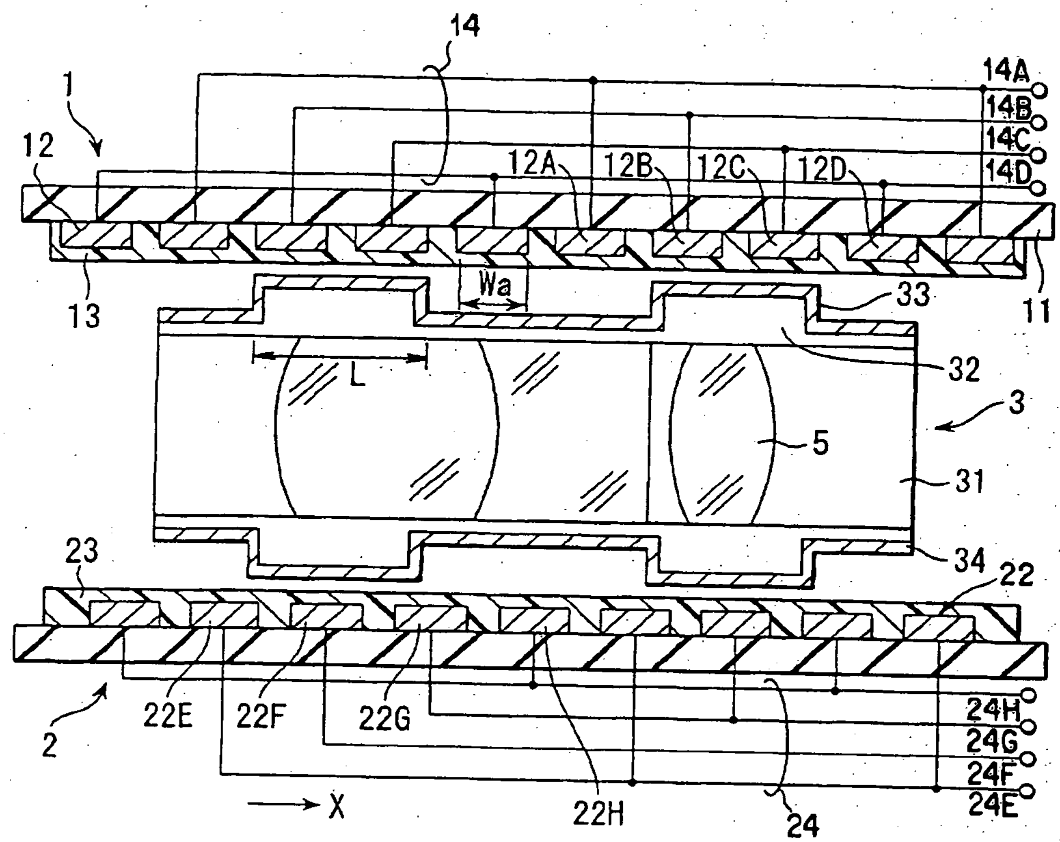
14
1
12
14A
14B
14C
14D
12A
12B
12C
12D
13
Wa
33
11
L
32
3
5
31
23
34
22
22E
22F
22G
24H
24G
24F
24E
2
X
22H
24

FIG. 8

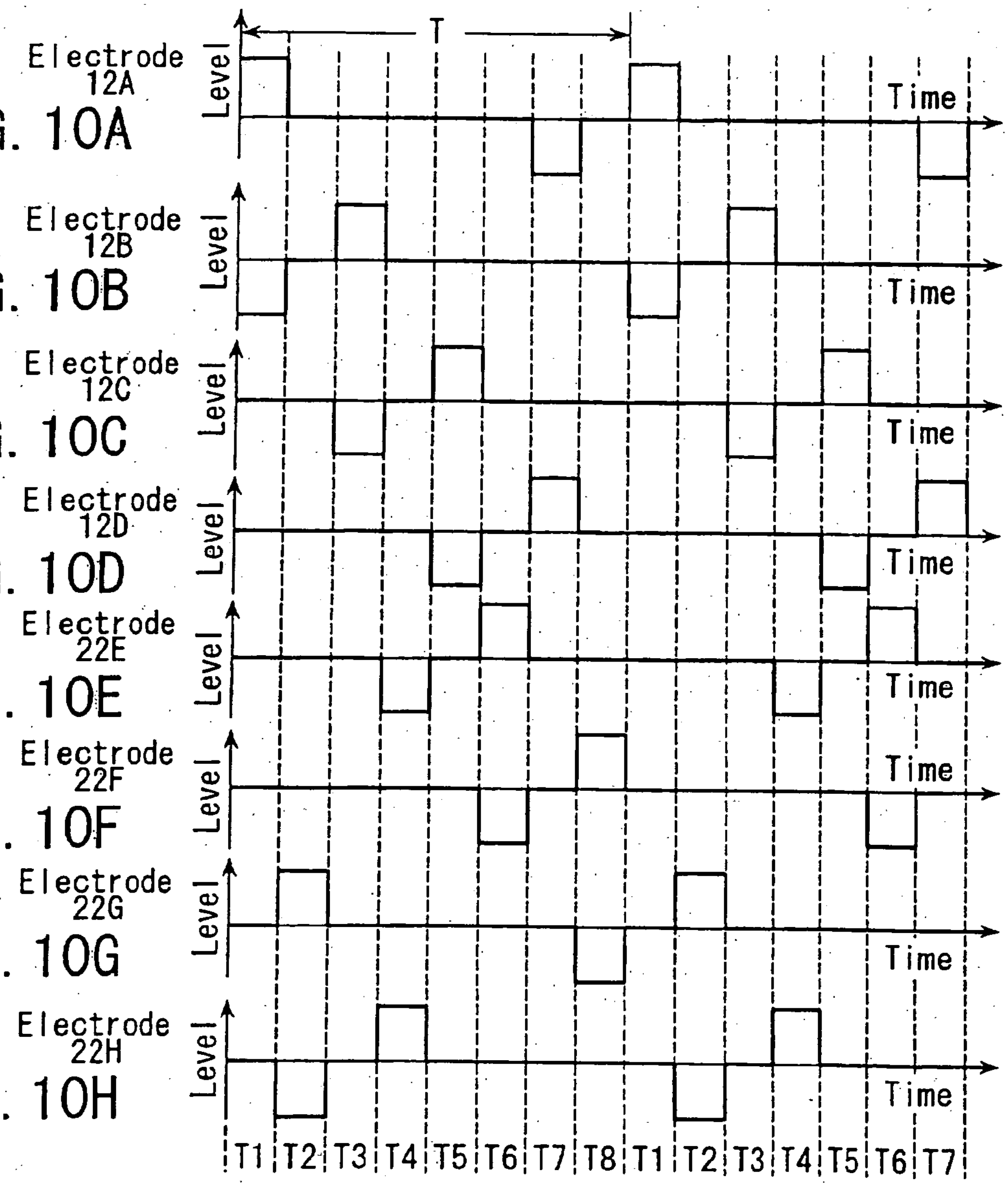

FIG. 10A
FIG. 10B
FIG. 10C
FIG. 10D
FIG. 10E
FIG. 10F
FIG. 10G
FIG. 10H

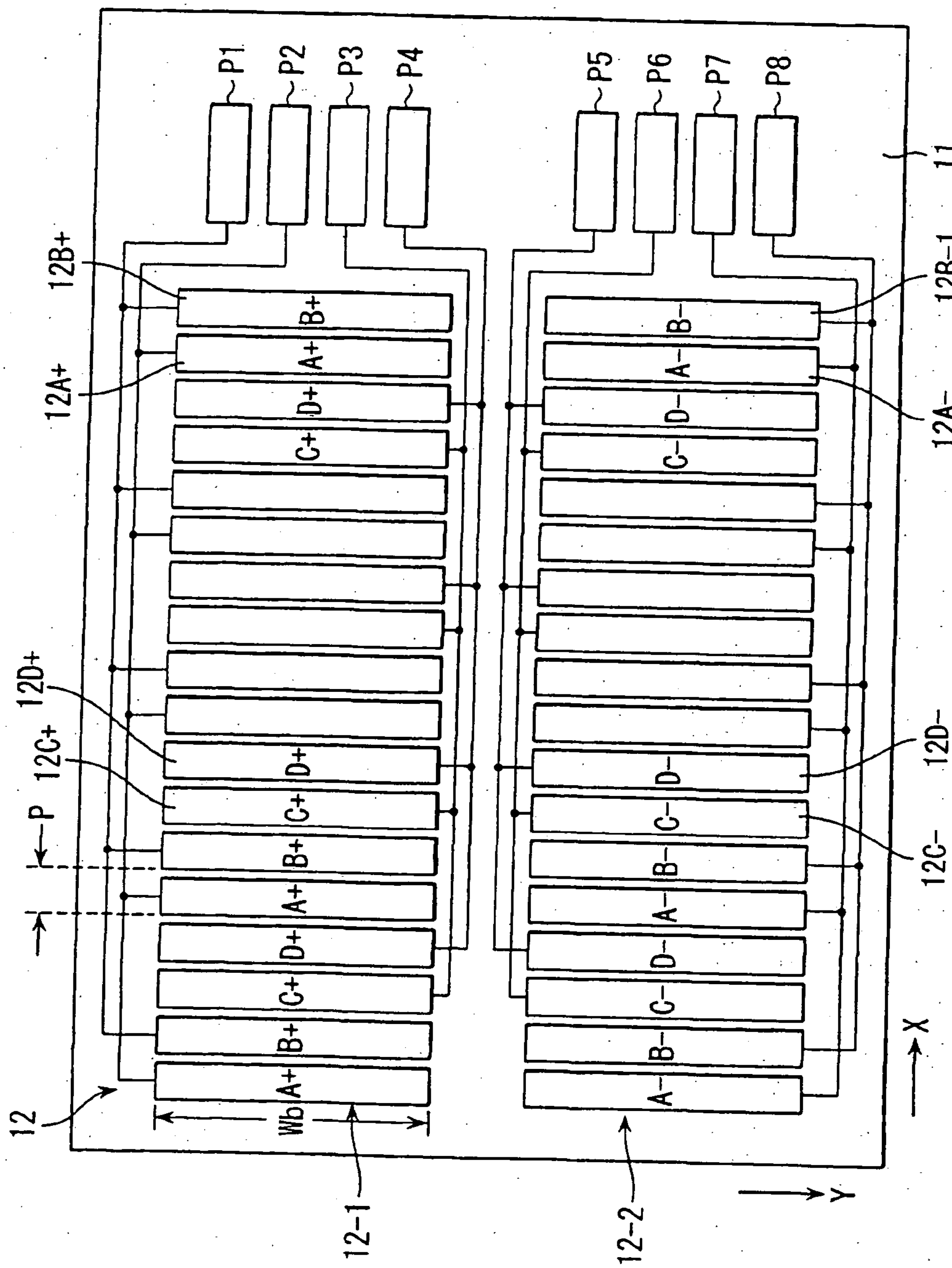
P1
P2
P3
P4
P5
P6
P7
P8
11
12
12-1
12-2
12A+
12B+
12C+
12D+
12A-
12B-1
12C-
12D-
P
Wb
X
Y
A+
B+
C+
D+
A-
B-
C-
D-

FIG. 12

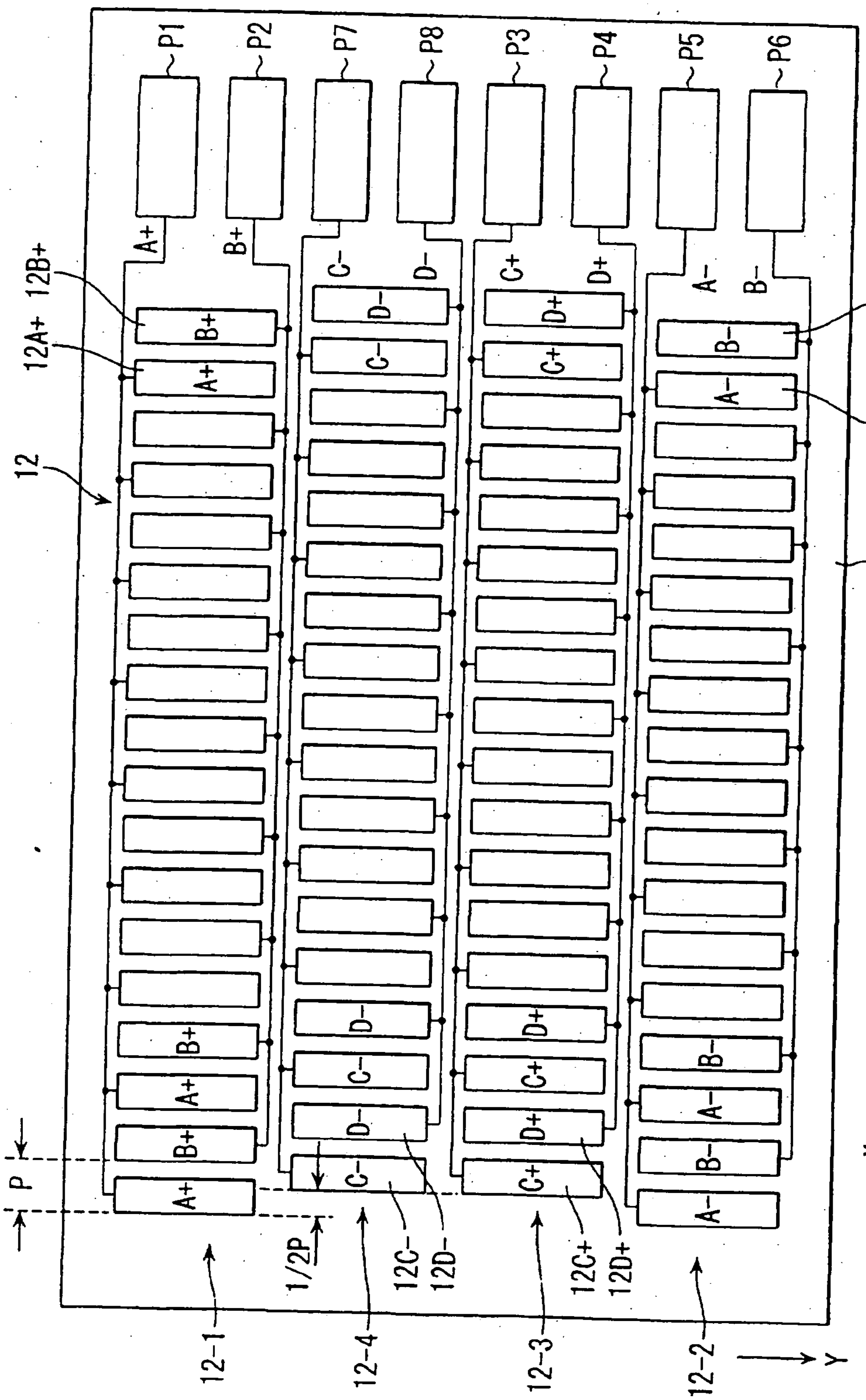
P1
P2
P7
P8
P3
P4
P5
P6
A+
B+
C−
D−
C+
D+
A−
B−
12A+
12B+
12
12B−
12A−
11
P
1/2P
12−1
12−4
12−3
12−2
12C−
12D−
12C+
12D+
X
Y

FIG. 14

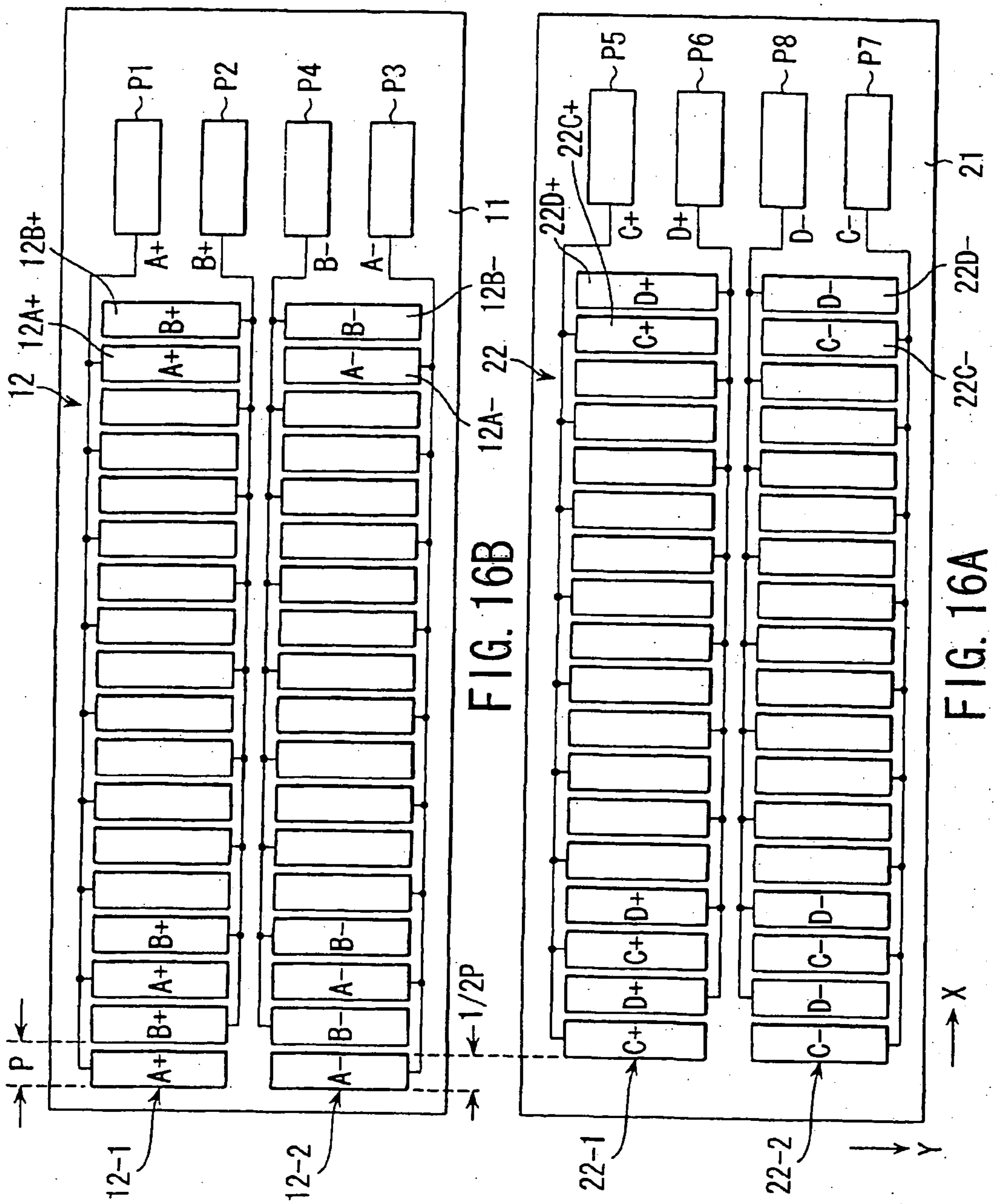

FIG. 16B

FIG. 16A

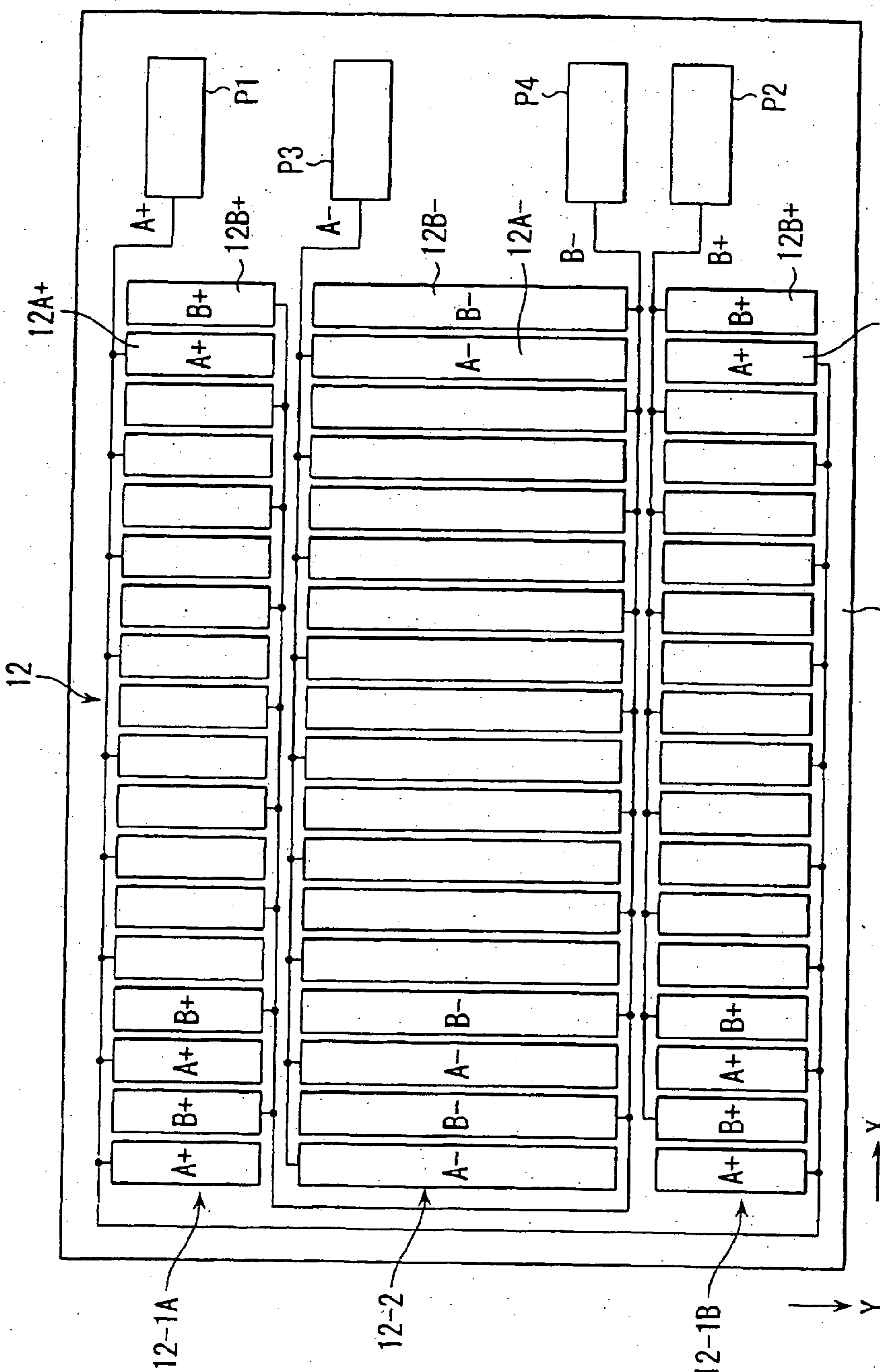

FIG. 18

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(54) Electrostatic actuator and camera module using the same

(57) An electrostatic actuator comprises a first stator section (1) having a first electrode array (12) arranged in a first direction, and a second stator section (2) having a second electrode array (22) of electrodes formed in the first direction. A movable section (3) having a fifth electrode (33) and a sixth electrode 34 arranged to face the first electrode array (12) and the second electrode array (22), respectively, is arranged between the first stator section (1) and the second stator section (2). A driving circuit (4) alternately performs a first driving operation in which a DC voltage is applied between the adjacent electrodes of the first electrode array (12) and a second driving operation in which a DC voltage is applied between the electrodes of the second electrode array (22). The voltage application is successively performed by deviating the positions of the electrodes to which the DC voltage is applied by the first driving operation so as to move the movable section (3) in the first direction while vibrating the movable section (3) between the first stator section (1) and the second stator section (2).

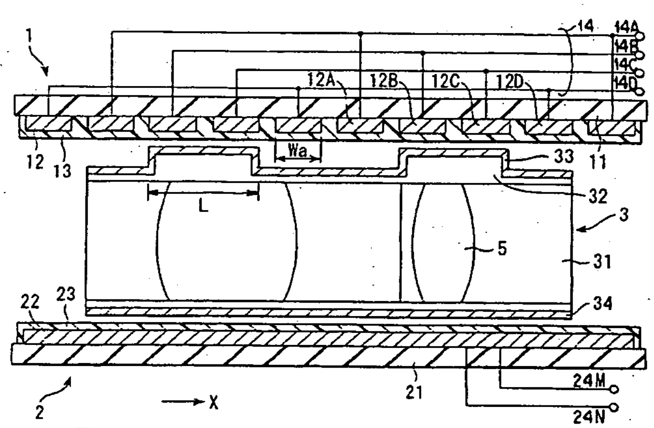

FIG. 1A

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(Cont. next page)

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EUROPEAN SEARCH REPORT

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DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A,D	KOGA A ET AL: "Electrostatic linear microactuator mechanism for focusing a CCD camera" JOURNAL OF LIGHTWAVE TECHNOLOGY, IEEE. NEW YORK, US, vol. 17, no. 1, January 1999 (1999-01), pages 43-47, XP002199041 ISSN: 0733-8724 * the whole document *	1-19	H02N1/00 G02B7/04
A,D	PATENT ABSTRACTS OF JAPAN vol. 1996, no. 09, 30 September 1996 (1996-09-30) & JP 08 140367 A (TOSHIBA CORP), 31 May 1996 (1996-05-31) * abstract; figures *	1-19	
A	PATENT ABSTRACTS OF JAPAN vol. 1998, no. 14, 31 December 1998 (1998-12-31) & JP 10 239578 A (TOSHIBA CORP), 11 September 1998 (1998-09-11) * abstract; figures *	1-19	TECHNICAL FIELDS SEARCHED (Int.Cl.7) H02N G02B
A	EP 0 381 212 A (HITACHI LTD) 8 August 1990 (1990-08-08) * abstract; figure 5 *	1-19	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	26 February 2003	Ramos, H

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